Method and device for detecting lane changing operations for a vehicle

The invention relates to a method and a device for detecting lane changing operations for a vehicle.

The method according to the invention and the device according to the invention may be used for example to improve the longitudinal control system arranged in a vehicle known as the adaptive cruise control system.

The adaptive cruise control systems known from the prior art can in the main be classified in two groups. A first group comprises the straightforward cruise control systems, which maintain a prescribed longitudinal velocity of the vehicle even in cases where the roadway inclines, there is wind resistance and the like. A second group comprises the active cruise control systems, which use a radar sensor to control both the distance between the driver's own vehicle and a vehicle traveling in front and the relative velocity. If the active cruise control system detects a slower vehicle traveling in front, the longitudinal velocity of the driver's own vehicle is reduced by producing a suitable braking deceleration until a prescribed time interval between the driver's own vehicle and the vehicle traveling in front is maintained. Such control of the distance and the relative velocity significantly increases the driving comfort and reliably prevents premature fatigue of the driver, specifically in the case of long journeys on freeways.

However, on account of system-related limitations, conventional active cruise control systems assist the driver only to a restricted extent. The system-related

limitations are caused, inter alia, by the maximum and minimum longitudinal velocity that can be prescribed on the active cruise control system or the maximum braking deceleration of the vehicle that is available in conjunction with the active cruise control system. If these system-related limitations are exceeded, the driver must completely resume the task of adaptive cruise control himself. This is the case in particular whenever a vehicle traveling in front is approached too quickly, a vehicle traveling in front decelerates sharply, another vehicle suddenly swerves into the roadway lane of the driver's own vehicle on account of a lane changing operation or the driver desires a longitudinal velocity which is greater or less than the maximum or minimum longitudinal velocity of the vehicle that can be prescribed on the active cruise control system.

The lane changing operations that lead to another vehicle suddenly swerving in have been found to be particularly critical in this connection, since they are only detected by the active cruise control system when the other vehicle is already substantially in the roadway lane of the driver's own vehicle.

It is therefore the object of the present invention to provide a method and a device of the type mentioned at the beginning in such a way that a lane changing operation carried out by another vehicle can be detected at an early time.

This object is achieved according to the invention by a method and a device for detecting lane changing operations for a vehicle in which at least one observation variable which describes the lane changing behavior of an observed other vehicle is determined. This involves determining in dependence on the at least one observation variable a lane changing variable which

characterizes a lane changing intention of the observed other vehicle on the basis of a roadway lane assigned to the other vehicle, so that a lane change of the other vehicle that is imminent on the basis of a predicted lane changing intention can be detected at an early time by evaluation of the lane changing variable.

Advantageous embodiments of the method according to the invention are provided by the subclaims.

The lane changing variable advantageously relates to swerving of the observed other vehicle into a roadway lane assigned to the driver's own vehicle, so that the swerving in operations of the other vehicle can be detected at an early time.

To allow definitive mathematical ascertainment of the lane changing intention of the observed other vehicle, the lane changing variable describes in particular the probability of an imminent lane change of the observed other vehicle. This involves deducing an imminent lane change of the other vehicle when it is found by evaluation of the lane changing variable that the probability is greater than a characteristic threshold value.

One of the most important features for the detection of a lane changing intention is the lateral dynamic behavior of the observed other vehicle in relation to the path followed by its roadway lane. It is accordingly of advantage if a first observation variable is a lane offset variable, which describes the lateral shift of the other vehicle in relation to the center of its lane on the roadway, and/or a second observation variable is a lane offset alteration variable, which describes a lateral velocity of the other vehicle in the orthogonal direction in relation to a tangent to the path followed by its roadway lane,

and/or a third observation variable is a lateral offset acceleration variable, which describes a maximum occurring lateral acceleration of the other vehicle on the basis of an imminent lane change.

Further important features result on the one hand from geometrical properties which the path followed by the roadway lane driven by the observed other vehicle has and on the other hand from characteristic time intervals which occur between the observed other vehicle and roadway markings which are provided on the surface of the roadway and define the path followed by the roadway lane of the other vehicle. With regard to an exact determination of the lane changing variable, a fourth observation variable may therefore be a lane curvature variable, which describes a curvature of the path followed by the roadway lane of the other vehicle, and/or a fifth observation variable may be a lane crossing time variable, which describes that period of time which is expected to elapse before a roadway marking delimiting the roadway lane of the other vehicle is crossed.

To allow particularly those lane changing operations that lead to potentially dangerous swerving of the observed other vehicle into a gap between the driver's own vehicle and the leading vehicle to be described as accurately as possible, it is of advantage if observation variables which describe the spatial and temporal behavior of the observed other vehicle in relation to the gap between the vehicles are determined. In this connection, a sixth observation variable may be a gap distance variable, which describes a distance of the other vehicle in relation to the gap between the vehicles, and/or a seventh observation variable may be a gap relative velocity variable, which describes a velocity of the other vehicle in relation to the gap between the vehicles,

and/or a seventh observation variable may be a gap relative acceleration variable, which describes an acceleration of the other vehicle in relation to the gap between the vehicles.

The determination of the at least one observation variable generally takes place on the basis of observation data which are supplied by observation means provided for the observation of the other vehicle. These observation data are generally subject to statistical variations, which are caused for example by physical phenomena and external disturbing influences and are manifested by more or less pronounced noise. This noise ultimately leads to a deterioration in the quality of the observation data supplied, and consequently to a corresponding variance of the at least one observation variable determined on the basis of the observation data. To allow a statement to be made concerning the reliability of the prediction of the lane changing intention of the observed other vehicle, it is therefore of advantage if a quality assessment or quality weighting of the at least one observation variable is performed in the determination of the lane changing variable by corresponding allowance being made for the associated variance.

The at least one observation variable and/or its variance can be determined particularly reliably by using a Kalman filter, which for this purpose evaluates the observation data supplied by the observation means. The variance of the at least one observation variable then results from the covariance matrices on which the respective Kalman filtering is based.

If a number of observation variables and/or their variances are determined, they can be combined with one another for computationally efficient determination of

the lane changing variable by means of a probabilistic network. On the basis of the inference of the probabilistic network, observation variables of low variance are given greater allowance than those of great variance, so that an implicit quality assessment or quality weighting of the determined alteration variables is carried out, ultimately leading to an optimization of the accuracy of the lane changing variable determined in dependence on the observation variables.

If an imminent lane change of the observed other vehicle is deduced by evaluation of the lane changing variable, there is the possibility of performing driver-independent interventions in the vehicle's equipment provided for influencing the longitudinal and/or lateral dynamics of the driver's own vehicle in such a way that the possible eventuality of getting dangerously close to the other vehicle caused by the lane change is averted by appropriate adaptation of the longitudinal velocity and/or the traveling direction of the driver's own vehicle.

As an alternative or in addition to the driver-independent interventions in the vehicle's equipment, it is conceivable to output an optical and/or acoustic and/or tactile indication to the driver, which draws the attention of the driver to the imminent lane change of the other vehicle.

The method according to the invention for detecting lane changing operations can be advantageously used in conjunction with an adaptive cruise control system arranged in the driver's own vehicle, which may in particular be an active cruise control system, and/or a lateral control system arranged in the driver's own vehicle, for example with a lane keeping assist.

The method according to the invention and the device according to the invention are explained in more detail below on the basis of the accompanying drawings, in which:

Figure 1 shows an exemplary embodiment of the method according to the invention in the form of a probabilistic network,

Figure 2 shows a coordinate-based representation of a lane changing operation in plan view, and

Figure 3 shows a schematically represented exemplary embodiment of the device according to the invention.

Figure 1 shows a schematic representation of the method according to the invention for detecting lane changing operations for a vehicle. The method comprises different levels of a probabilistic network, a number of observation variables which describe the lane changing behavior of the observed other vehicle 15 being described on a first level 11.

Each observation variable is assigned here a specific entry node of the probabilistic network, the determination of the observation variables in the respective entry nodes taking place by using Kalman filters for object tracking and lane detection. For this purpose, the Kalman filters use state vectors of the form

$$\vec{x}_{lane} = (o_{lane,ego}, \psi, c_0, c_1, w_{lane}) \quad , \tag{1.1}$$

$$\vec{x}_{long,obj,i} = (x_{obj,i}, v_{x,ego}, a_{x,ego}, v_{x,obj,i}, a_{x,obj,i}) \quad , \tag{1.2}$$

$$\vec{x}_{lat,obj,i} = (y_{obj,i}, v_{y,obj,i}, a_{y,obj,i}) \quad , \tag{1.3}$$

where $o_{lane,ego}$ describes a lateral shift of the driver's own vehicle 16 in relation to the center of the lane on the roadway, ψ describes the yaw angle of the driver's own vehicle 16 in relation to a tangent to the path followed by the roadway lane, c_0 describes the curvature of the roadway lane, c_1 describes the change over time of the curvature of the roadway lane, w_{lane} describes the width of the roadway lane, $x_{obj,i}$ describes a longitudinal distance from the ith ($i \in \mathbb{N}$) observed other vehicle 15, $v_{x,ego}$ describes a longitudinal velocity of the driver's own vehicle 16, $a_{x,ego}$ describes a longitudinal acceleration of the driver's own vehicle 16, $v_{x,obj,i}$ and $a_{x,obj,i}$ describe a longitudinal velocity and a longitudinal acceleration, respectively, of the ith observed other vehicle 15, $y_{obj,i}$ describes a lateral distance of the ith observed other vehicle 15 and $v_{y,obj,i}$ and $a_{y,obj,i}$ describe a lateral velocity and lateral acceleration, respectively, of the ith observed other vehicle 15.

In a first entry node 11a of the probabilistic network, a lane offset variable o_{lane} is then determined, describing a lateral shift of the ith observed other vehicle 15 in relation to the center of its lane on the roadway,

$$o_{lane} = y_{obj,i} + o_{lane,ego} + y_{lane}(x_{obj,i}) \pm w_{lane} \quad , \qquad (1.4)$$

it being assumed for the sake of simplicity that the width described by the variable w_{lane} is the same for all roadways. The positive or negative sign applies if the ith observed other vehicle 15 is on the left and/or right side of the driver's own vehicle 16, seen in the direction of travel.

The function y_{lane} $(x_{obj,i})$ entering equation (1.4) describes here the path followed by the center of the lane on the roadway of the ith observed other vehicle 15 in dependence on the distance variable $x_{obj,i}$ and is defined as

$$y_{lane}(x_{obj,i}) = -x_{obj,i}\sin(\psi) + \frac{1}{2}c_o x_{obj,i}^2 + \frac{1}{6}c_1 x_{obj,i}^3 \quad . \qquad (1.5)$$

On the basis of the yaw angle of the driver's own vehicle 16, the path followed by the roadway lane is turned in accordance with the value of the yaw angle ψ, allowance for which is made in equation (1.5) by an approximation term of the form

$$-x_{obj,i}\sin(\psi) \qquad (1.6)$$

In a second entry node 11b of the probabilistic network, a lane offset alteration variable v_{lat} is also determined, describing a lateral velocity of the ith observed other vehicle 15 in a direction orthogonal to a tangent to the path followed by its roadway lane. The lane offset alteration variable v_{lat} then becomes

$$v_{lat} = v_{y,obj,i}\cos(\alpha) + v_{x,obj,i}\sin(\alpha) \quad , \qquad (1.7)$$

where the size of the angle α is obtained from the difference of the alignments of the tangent to the path followed by the roadway at distances from the driver's own vehicle 16 given by the values $x = 0$ and $x = x_{obj,i}$,

$$\alpha = \arctan\left(\left.\frac{dy_{lane}}{dx}\right|_{x_{obj}}\right) \quad . \qquad (1.8)$$

To allow a model for detecting an imminent lane change to be derived from the path of the course driven by the ith observed other vehicle 15, and to allow observation variables that are characteristic of an imminent lane change to be determined, it is required to transform the distance variables ($x_{obj,i}$, $y_{obj,i}$) ascertained in relation to the driver's own vehicle 16 into a system of coordinates suitable for this.

A suitable coordinate transformation is to be explained in more detail below with reference to Figure 2, the distance variables ($x_{obj,i}$, $y_{obj,i}$) ascertained during the journey of the driver's own vehicle 16 at successive points in time of ascertainment being represented by individual measuring points o. The latter are to be used hereafter for calculating regression polynomials, from which the likely path of the course driven by the ith observed other vehicle 15 can then be derived for detecting an imminent lane change.

Since the ascertainment of the distance variables ($x_{obj,i}$, $y_{obj,i}$) takes place in relation to the driver's own vehicle 16, this forms a relative system of coordinates with respect to the ascertained distance variables ($x_{obj,i}$, $y_{obj,i}$). On the basis of the travel of the driver's own vehicle 16, however, the location and alignment of the relative system of coordinates then changes with time, which increases the computational complexity of the detection of an imminent lane change considerably. The ascertained distance variables ($x_{obj,i}$, $y_{obj,i}$) are therefore transformed into a time-invariant absolute system of coordinates S_{abs}, the origin of which is defined by the starting point of the journey of the driver's own vehicle 16.

In the transformation of the ascertained distance variables ($x_{obj,i}$, $y_{obj,i}$), allowance is to be made for the location coordinates applicable at the respective

point in time of ascertainment and the alignment ψ_{ego} of the driver's own vehicle 16,

$$\vec{X}_{ego} = (X_{ego}, Y_{ego}, \Psi_{ego}) \quad . \tag{1.9}$$

The transformation of the ascertained distance variables ($x_{obj,i}$, $y_{obj,i}$) from the relative system of coordinates into the absolute system of coordinates S_{abs} then comprises a shift by (X_{ego}, Y_{ego}) and a rotation by ψ_{ego} at the respective point in time of ascertainment. The result of this transformation is a path of the course driven by the ith observed other vehicle 15, given by a trajectory

$$T_1 = (\vec{X}_{obj,i}, \vec{Y}_{obj,i}) \tag{1.10}$$

in the absolute system of coordinates S_{abs}. The trajectory

$$T_2 = (\vec{x}_{1dir,obj,i}, \vec{y}_{1dir,obj,i}) \tag{1.11}$$

then represents the path of the course driven by the ith observed other vehicle 15 in the direction given by ψ_{ego}, that is to say in a system of coordinates S_ψ turned by ψ_{ego}. The location vectors $\vec{x}_{1dir,obj,i}$ and $\vec{y}_{1dir,obj,i}$ are determined on the basis of absolute location vectors ($\vec{x}_{1dir,obj,i}$, $\vec{y}_{1dir,obj,i}$), which for their part are obtained from the absolute location vectors ($X_{obj,i}$, $Y_{obj,i}$) of the ith observed other vehicle 15 by rotation by $-\psi_{ego}$. Consequently, $\vec{x}_{1dir,obj,i}$ represents the distance covered by the ith observed other vehicle 15 in the direction of ψ_{ego}. By analogy, $\vec{y}_{1dir,obj,i}$ represents the distance covered by the ith observed other vehicle 15 in the direction perpendicular to ψ_{ego}.

The location vectors ($\vec{x}_{1dir,obj,i}$, $\vec{y}_{1dir,obj,i}$) form the basis for determining an individual distance variable L_{relev} relevant for an imminent lane change, which according to Figure 2 is obtained from

$$x^k_{1dir,obj,i} = X^k_{1dir,obj,i} - X^L_{1dir,obj,i} \qquad (1.12)$$

and

$$y^k_{1dir,obj,i} = Y^k_{1dir,obj,i} - Y^L_{1dir,obj,i} \qquad (1.13)$$

To minimize the computational complexity hereafter, a further trajectory

$$T_3 = (\vec{x}_{1dir,obj,i}, \vec{y}_{1dir,obj,i,straight}) \qquad (1.14)$$

is determined, representing the trajectory T_2 on the assumption that the roadway lane follows a linear path. The distance variable $\vec{y}_{1dir,obj,i,straight}$ here describes the lateral shift of the ith observed other vehicle 15 in relation to the center of its lane on the roadway,

$$y^k_{1dir,obj,i,straight} = y^k_{obj,i} + o_{lane} - y_{lane}(x^k_{1dir,obj,i}) \pm w_{lane} \quad . \qquad (1.15)$$

Thereafter, a probable starting point S for the lane change of the ith observed other vehicle 15 is determined. For this purpose, a regression polynomial y_{T3} is determined for the trajectory T_3, which takes place by applying the method of least squares. The probable starting point S of the lane change is then obtained at that location at which the regression polynomial y_{T3} assumes an extreme value.

Since a curvature of the path followed by the roadway lane is only of significance for the detection of a lane changing operation for the portion of roadway following the starting point S, it is sufficient if a regression polynomial y_{T2} for the trajectory T_2 is determined only for this portion of roadway, so that the computational effort in the prediction of an imminent lane change of the ith observed other vehicle 15 is reduced considerably.

In a third entry node 11c of the probabilistic network, a lateral offset acceleration variable $a_{y,max}$ is then determined, describing the lateral acceleration of the ith observed other vehicle 15 occurring as a maximum on the basis of the imminent lane change. The determination takes place by determining a model trajectory T_m best fitting the trajectory T_3 and parameterized with the lateral offset acceleration variable $a_{y,max}$. That model trajectory T_m which best fits the determined trajectory T_3 then supplies the value for the lateral offset acceleration variable $a_{y,max}$ for which allowance is to be made in the third entry node 11c. The following applies for the model trajectory:

$$T_m = (\vec{x}_m, \vec{y}_m) \quad , \tag{1.16}$$

where the vectorial distance variable $\vec{x}_m$ represents that part of $\vec{x}_{1dir,obj,i}$ which lies between the probable starting point S of the lane change and the chosen prediction horizon. The variance occurring in the matching of the model trajectory T_m is in this case calculated as

$$\sigma_{Tm} = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}\left(y_m^k - y_{1dir,obj,i,straight}^k\right)^2} \quad , \tag{1.17}$$

a binary search being carried out for the model trajectory T_m best fitting the trajectory T_3, in which search an interval of values prescribed for the lateral offset acceleration variable $a_{y,max}$ is successively run through, and which search ends as soon as $\Delta\sigma_{Tm} = \sigma_{Tm}^{r} - \sigma_{Tm}^{r-1}$ in two successive search operations r-1 and r is below a given threshold ε,

$$\sigma_{Tm}^{r} - \sigma_{Tm}^{r-1} < \varepsilon \quad . \tag{1.18}$$

In the fourth entry node 11d, a lane curvature variable ν_{lane} is determined, describing a curvature of the path followed by the roadway lane of the ith observed other vehicle 15,

$$\nu_{lane,scal} = \tau_{lane} v_{x,obj,i} \quad , \tag{1.19}$$

with

$$\tau_{lane} = \left(\frac{dy_{T2}}{dx} - \frac{dy_{lane}}{dx} \right) \Bigg|_{x_{obj}} \quad . \tag{1.20}$$

In a fifth entry node 11e of the probabilistic network, a lane crossing time variable t_{lcr} is determined, describing that period of time which is expected to elapse before a roadway marking delimiting the roadway lane of the ith observed other vehicle 15 is crossed (known as time to line crossing). To calculate the lane crossing time variable t_{lcr}, the point of intersection between the regression polynomial y_{T2} of the trajectory T_2 and the position of the roadway marking given by

$$y_{T2} \pm \frac{w_{lane}}{2} \qquad (1.21)$$

is determined,

$$y_{T2} - y_{lane} \pm \frac{w_{lane}}{2} \stackrel{!}{=} 0 \quad . \qquad (1.22)$$

The resolution of the equation (1.22) then supplies the spatial distance at which the ith observed other vehicle 15 is expected to cross the roadway marking. To determine the lane crossing time variable t_{lcr}, it is assumed for the sake of simplicity that the velocity variable $v_{x,obj,i}$ is constant, so that therefore

$$t_{lcr} = \frac{x_{lcr}}{v_{x,obj,i}} \quad . \qquad (1.23)$$

To allow particularly those lane changing operations that lead to potentially dangerous swerving of the ith observed other vehicle 15 into a gap between the driver's own vehicle 16 and the leading vehicle 17 to be detected, further observation variables which describe the spatial and temporal behavior of the ith observed other vehicle 15 in relation to the gap between the vehicles are determined.

Accordingly, in a sixth entry node 11f, a gap distance variable x_{gap} is determined, describing a distance of the ith observed other vehicle 15 in relation to the gap between the vehicles,

$$x_{gap} = x_{obj,i} - x_{ego,gap} \quad \text{mit} \quad x_{ego,gap} = \frac{x_{lead}}{2} \quad , \qquad (1.24)$$

in a seventh entry node 11g, a gap relative velocity variable $v_{gap,rel}$ is determined, describing a velocity of the ith observed other vehicle 15 in relation to the gap between the vehicles,

$$v_{gap,rel} = v_{obj,i} - v_{gap} \quad \text{mit} \quad v_{gap} = \frac{v_{x,ego} + v_{x,lead}}{2} \text{ ,} \qquad (1.25)$$

and, in an eighth entry node 11h, a gap relative acceleration variable $a_{gap,rel}$ is determined, describing an acceleration of the ith observed other vehicle 15 in relation to the gap between the vehicles,

$$a_{gap,rel} = a_{obj,i} - a_{gap} \quad \text{mit} \quad a_{gap} = \frac{a_{x,ego} + a_{x,lead}}{2} \text{ ,} \qquad (1.26)$$

The determination takes place by determining a theoretical gap between vehicles best fitting the gap between the vehicles and parameterized with the gap distance variable x_{gap}, the gap relative velocity variable $v_{gap,rel}$ and the gap relative acceleration variable $a_{gap,rel}$. That theoretical gap between vehicles which best fits the actual gap between the vehicles then supplies the gap distance variable x_{gap}, the gap relative velocity variable $v_{gap,rel}$ and the gap relative acceleration variable $a_{gap,rel}$ for which allowance is to be made in the entry nodes 11f to 11h.

If there is no leading vehicle 17, x_{gap} is set to a standard value, $v_{gap,rel}$ is set to v_{ego} and $a_{gap,rel}$ is set to a_{ego}.

Furthermore, as a measure of quality for the observation variables determined in the entry nodes 11a to 11h, allowance is made for the associated variances. These can be derived from the covariance matrices P on which the Kalman filtering is based.

The Kalman filters for object tracking and situation detection supply the state vectors $\vec{x}_{lane}$ and $\vec{x}_{obj,i}$. In addition, the associated covariance matrices P_{lane} and $P_{obj,i}$ are available. Hereafter, it is assumed that the variables supplied by different Kalman filters are respectively independent of one another, so that

$$\sigma_{xq,xr} = 0 \qquad (2.1)$$

for

$$x_q \in \vec{x}_{obj,i} \quad , \quad x_r \in \vec{x}_{lane} \quad . \qquad (2.2)$$

The calculation of the (mean) value μ_Z of the observation variable of the entry node Z_l (l = a...h) of the probabilistic network requires functions which combine the state vectors $\vec{x}_{lane}$ and $\vec{x}_{obj,i}$ of the two Kalman filters in a suitable way,

$$\mu_{Zl} = f_l(\vec{x}_{obj,i}, \vec{x}_{lane}) \quad . \qquad (2.3)$$

It is implicitly assumed by the structure of the probabilistic network that the entry nodes Z_l are independent of one another. Consequently, it is assumed in first approximation that the variances σ_{Zl} of the observation variables of the entry nodes Z_l have the property

$$\sigma_{Zl,Zm} = 0 \text{ für } l \neq m \qquad (2.4)$$

The variance σ_{Zl} of the observation variable of the lth entry node Z_l can be represented with the aid of a Taylor series development,

$$E[(Z_1 - E[Z_1])^2] = ACA^T \quad , \tag{2.5}$$

where C represents the covariance matrix of those variables x_s from which the value of μ_{Z1} is determined. The matrix A comprises the derivatives at the point $x_s = \mu_s$,

$$A_s = \left[\frac{\partial Z_1}{\partial x_s}\right]_{\bar{x}=\bar{\mu}} \quad . \tag{2.6}$$

After the determination of the variances σ_{Z1} of the observation variables of the entry nodes Z_1, normally distributed probability density functions $N_1(\mu_{Z1}, \sigma_{Z1})$ are set for the occupancy of the individual entry nodes Z_1. Since the probabilistic network comprises discrete-value entry nodes Z_1, the probability of a given interval of values [a, b] is determined according to

$$P_1(a \leq Z_1 \leq b) = \int_a^b \frac{dz}{\sigma_{Z1}\sqrt{2\pi}} \cdot \exp\left\{-\frac{z - \mu_{Z1}}{2 \cdot \sigma_{Z1}^2}\right\} \quad . \tag{2.7}$$

Since this integral cannot be resolved in a closed form and the carrying out of a numerical integration would be computationally inefficient, equation (2.7) is determined with the aid of a normalized distribution function of the form

$$\Phi_1 = \int_a^b N_1(\mu_{Z1} = 0, \sigma_{Z1} = 1) \tag{2.8}$$

so that ultimately

$$P_1(a \le Z_1 \le b) = \Phi_1\left(\frac{b-\mu_{Z1}}{\sigma_{Z1}}\right) - \Phi_1\left(\frac{a-\mu_{Z1}}{\sigma_{Z1}}\right) \quad . \qquad (2.9)$$

is obtained.

The inclusion of the variance σ_{Z1} of the entry nodes Z_1 makes it possible to carry out an implicit quality assessment or quality weighting of the observation variables determined in the entry nodes Z_1, since greater allowance is made for observation variables of small variance σ_{Z1} than for those of great variance σ_{Z1} by the inference of the probabilistic network.

To establish whether or not the ith observed other vehicle 15 has swerved in, the observation variables determined on the first level 11 of the probabilistic network are grouped on a second level 12 to form intermediate variables.

In a first intermediate node 12a, the lane offset variable o_{lane}, determined in the first entry node 11a, and the lane offset alteration variable v_{lat}, determined in the second entry node 11b, are grouped here to form a lane offset indicating variable LE.

In a second intermediate node 12b, furthermore, the lateral offset acceleration variable $a_{y,max}$, determined in the third entry node 11c, the lane curvature variable v_{lane}, determined in the fourth entry node 11d, and the lane crossing time variable t_{lcr}, determined in the fifth entry node 11e, are grouped to form a trajectory indicating variable TR, the gap distance variable x_{gap}, determined in the sixth entry node 11f, the gap relative velocity variable $v_{gap,rel}$, determined in the seventh entry node 11g, and the gap relative acceleration variable $a_{gap,rel}$, determined in the eighth entry node 11h, finally being grouped in a third

intermediate node 12c to form a gap between vehicles indicating variable GS. The grouping takes place in each case in such a way that the lane offset indicating variable LE, the trajectory indicating variable TR and the gap between vehicles indicating variable GS assume the "true" state in the case of another vehicle being likely to swerve in and the "untrue" state in the case of another vehicle not swerving in.

The intermediate variables determined in the intermediate nodes 12a to 12c are then combined in an output node 13a, which forms a third level 13 of the probabilistic network, to form a common output variable in the form of a lane changing variable CV in such a way that the latter describes a swerving in probability for an imminent swerving in operation of the ith observed other vehicle 15.

The individual levels 11 to 13 of the probabilistic network accordingly form a decision hierarchy, within which the entry nodes 11a to 11h of the first level 11 describe the lane changing or swerving in behavior of the ith observed other vehicle 15, the intermediate nodes 12a to 12c of the second level 12 represent partial interim decisions, and finally the output node 13a of the third level 13 forms a final decision, taken on the basis of the interim decisions, in the form of a lane changing or swerving in intention of the ith observed other vehicle 15, characterized by the lane changing variable.

If the swerving in probability described by the lane changing variable CV is greater than a characteristic threshold value, so that imminent swerving in of the ith observed other vehicle 15 can be deduced with great certainty, driver-independent interventions take place in vehicle equipment provided for influencing the longitudinal dynamics of the vehicle 16 in such a way

that the longitudinal velocity of the vehicle 16 is reduced until a prescribed safety time interval between the driver's own vehicle 16 and the swerving-in other vehicle 15 is maintained. If required, the carrying out of an automatic emergency braking operation can also be initiated to avoid running into the ith observed other vehicle 15.

The method according to the invention accordingly extends the function of active cruise control systems of a conventional type for the case of other vehicles 15 swerving in. The vehicle equipment is, for example, a braking means and/or driving means of the driver's own vehicle 16. In this connection, it is also conceivable to perform driver-independent interventions in vehicle equipment provided for influencing the lateral dynamics of the vehicle 16 to carry out an evasive maneuver, this vehicle equipment being for example steering means of the driver's own vehicle 16.

In addition to the driver-independent interventions in the vehicle equipment, the output of an optical and/or acoustic and/or tactile indication to the driver is instigated, drawing the attention of the driver to the imminent swerving in of the ith observed other vehicle 15.

Figure 3 shows an exemplary embodiment of a device for carrying out the method according to the invention.

The device comprises observation means 20 for observing another vehicle, the observation means 20 having a first sensor device 20a for object tracking, which ascertains the spatial and temporal behavior of the ith observed other vehicle 15 in relation to the driver's own vehicle 16, and a second sensor device 20b for lane tracking, which ascertains the spatial and temporal behavior of the ith observed other vehicle 15 in

relation to the path followed by the roadway markings of the roadway lane of the driver's own vehicle 16.

The first sensor device 20a for object tracking is a radar sensor and/or a laser scanning device operating in the infrared wavelength range. The angle of coverage of the laser scanning device is typically greater than 30°, so that other vehicles located in a neighboring roadway lane can still be ascertained at a distance of 15 meters and less from the driver's own vehicle 16. To allow both the new range and the far range in front of and alongside the driver's own vehicle 16 to be reliably covered in the case where a radar sensor is used, different radar frequencies are required. For instance, a radar frequency of typically 24 GHz is used for covering the near range and a radar frequency of typically 77 GHz is used for covering the far range.

The second sensor device 20b for lane tracking is also a CCD camera or an imaging laser scanning device operating in the infrared wavelength range. As an alternative or in addition, the lane tracking takes place on the basis of electronic map data, which are made available by a satellite-aided navigation system arranged in the driver's own vehicle 16.

The observation data supplied by the observation means 20 are subsequently fed to an evaluation unit 21, which then determines the observation variables and their variances to determine the lane changing variable CV.

To carry out the driver-independent interventions in the driving means 22 of the vehicle 16, there is a driving means controller 23, by means of which the driving torque of an engine provided as the vehicle drive can be influenced. Furthermore, to carry out the driver-independent interventions in the braking means

24a to 24d of the vehicle 16, there is a braking means controller 25, by means of which a braking torque generated in the braking means 24a to 24d can be influenced.

To output the indication to the driver, there is an optical signal transmitter 30 and/or an acoustic signal transmitter 31 and/or a tactile signal transmitter 32, the tactile signal transmitter 32 being, for example, a steering wheel torque transmitter, by means of which a steering wheel torque can be induced in the form of a vibration on a steering wheel arranged in the driver's own vehicle 16. As an alternative, the tactile signal transmitter 32 may also be a structure-borne sound generator provided for generating a rumble strip noise. In this case, the two sides of the driver's own vehicle 16 may be respectively assigned separate structure-borne sound generators, so that the rumble strip noise can be generated on that side of the vehicle on which the lane changing or swerving in operation of the ith observed other vehicle 15 is imminent.